Fermilab

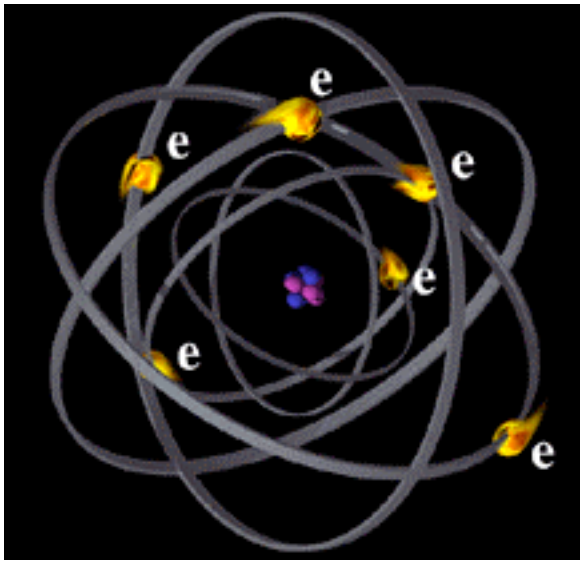
Noise In RF Systems

Ralph J. Pasquinelli

Noise in RF Systems

What are sources of electrical noise?

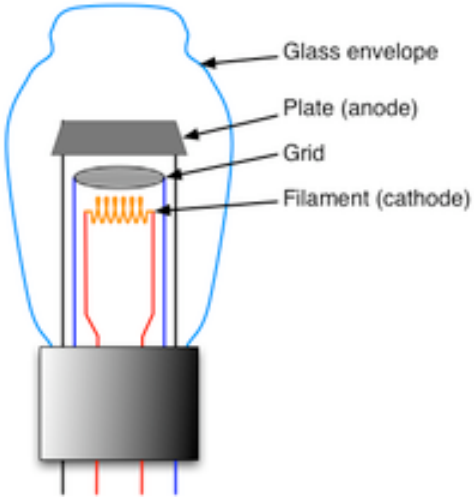
Random motion of electrons produces thermal noise
Sometimes referred to as "white noise"



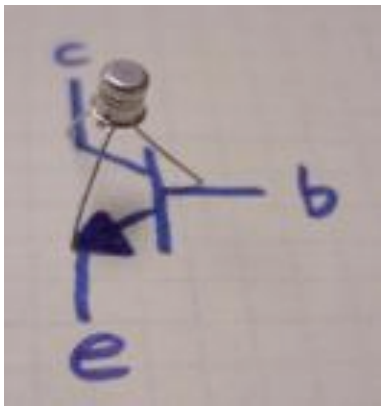
Noise in RF Systems

What are sources of electrical noise?

Vacuum Tube



Transistor

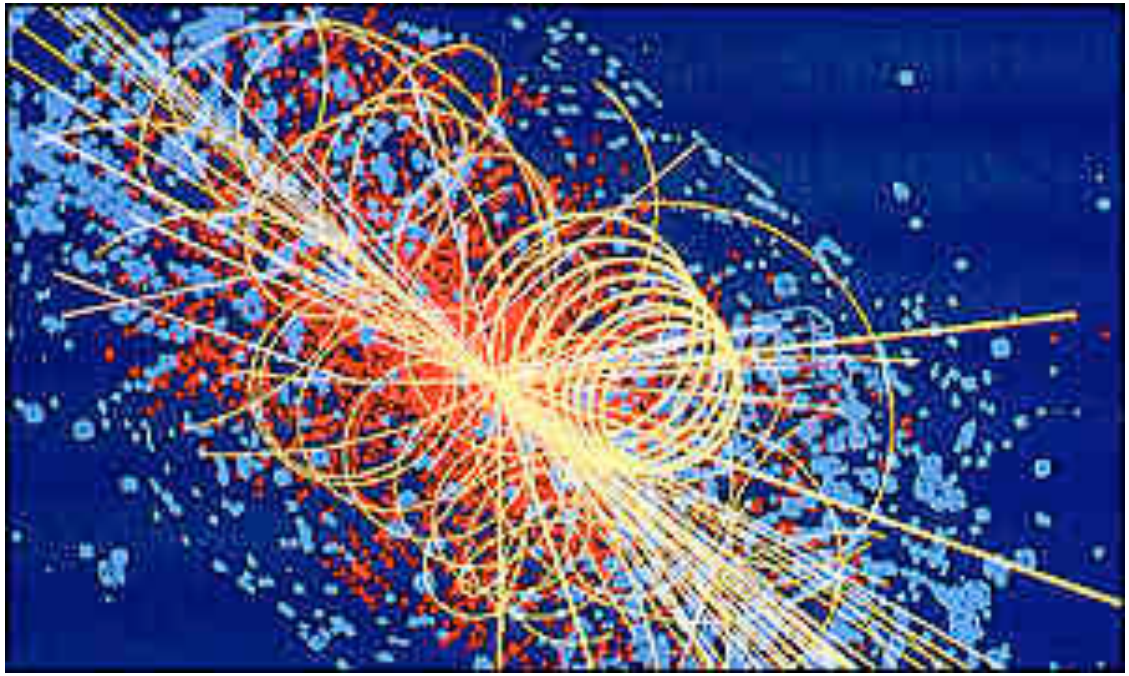


Particle Accelerator

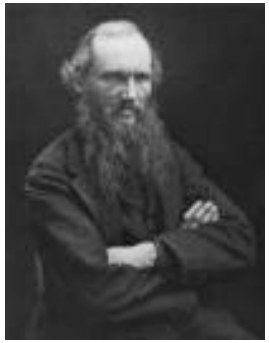
Noise in RF Systems

What are sources of electrical noise?

Other undesirable charged particles



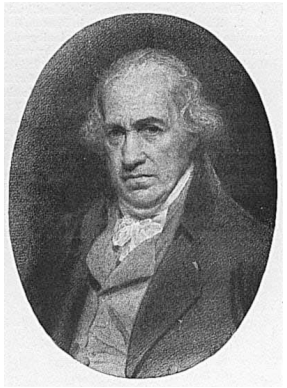
Noise Basics


Thermal Noise = kTB

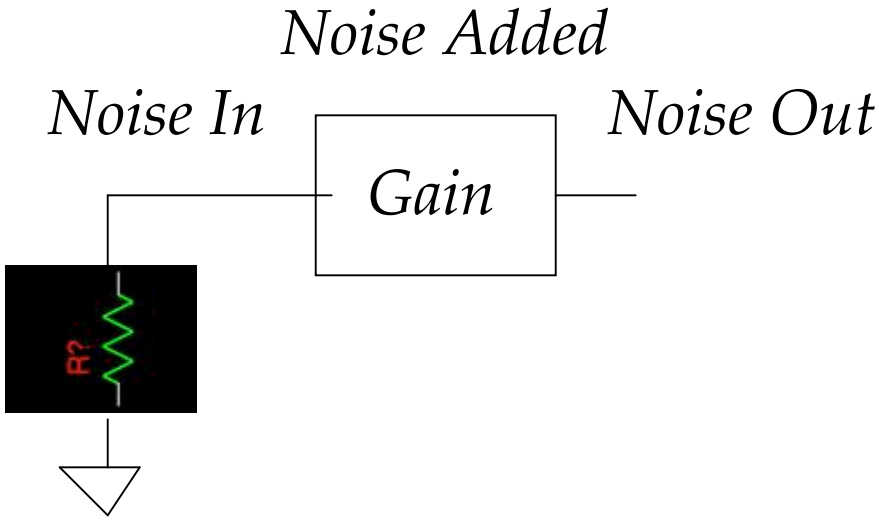
Boltsman's constant x Temperature x Bandwidth

$$\frac{Watt \quad \cancel{Seconds}}{\cancel{Degrees\ K}} \times \cancel{Degrees\ K} \times \frac{1}{\cancel{Seconds}}$$



Noise in RF Systems

Noise Basics



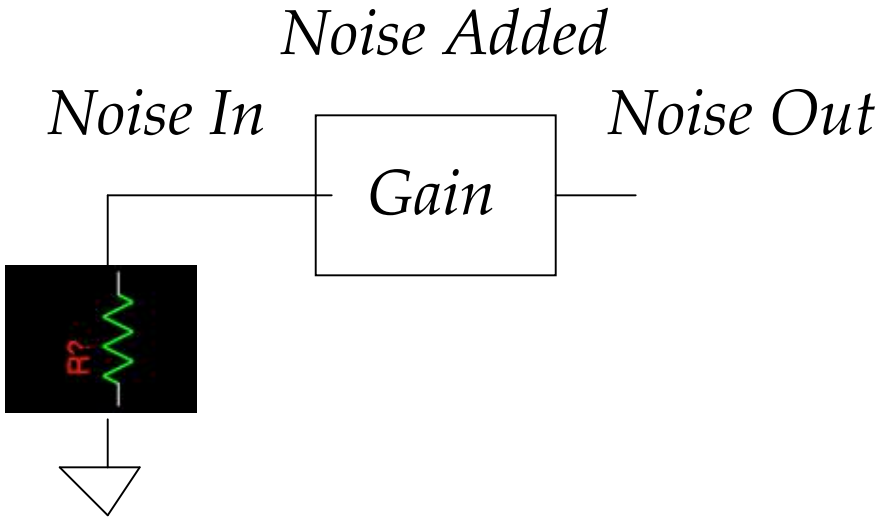
Noise unit is watts

$$\text{Noise Figure or Noise Factor} = NF = \frac{\frac{\text{Signal In}}{\text{Noise In}}}{\frac{\text{Signal Out}}{\text{Noise Out}}} = \frac{\cancel{(\text{Signal In})}(\text{Noise Out})}{(\text{Gain})\cancel{(\text{Signal In})}(\text{Noise In})} = \frac{\text{Noise Out}}{(\text{Gain})(\text{Noise In})}$$

The Perfect Gain Box adds no noise, so NF=1 or 0 dB

Noise in RF Systems

Noise Basics



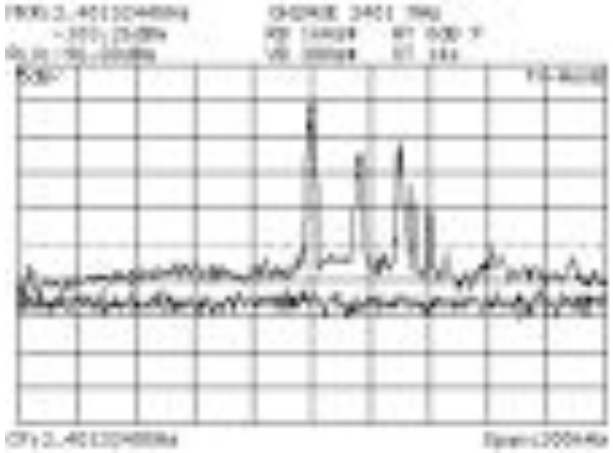
$$Noise\ Out = Noise\ In \times Gain + Noise\ Added$$

$$Noise\ Added = Noise\ Out - Noise\ In \times Gain$$
$$= NF \times Noise\ In \times Gain - Noise\ In \times Gain$$
$$= (NF - 1) \times Noise\ In \times Gain$$

$$Noise\ In = kTB$$

Noise Basics

Where is the noise floor?



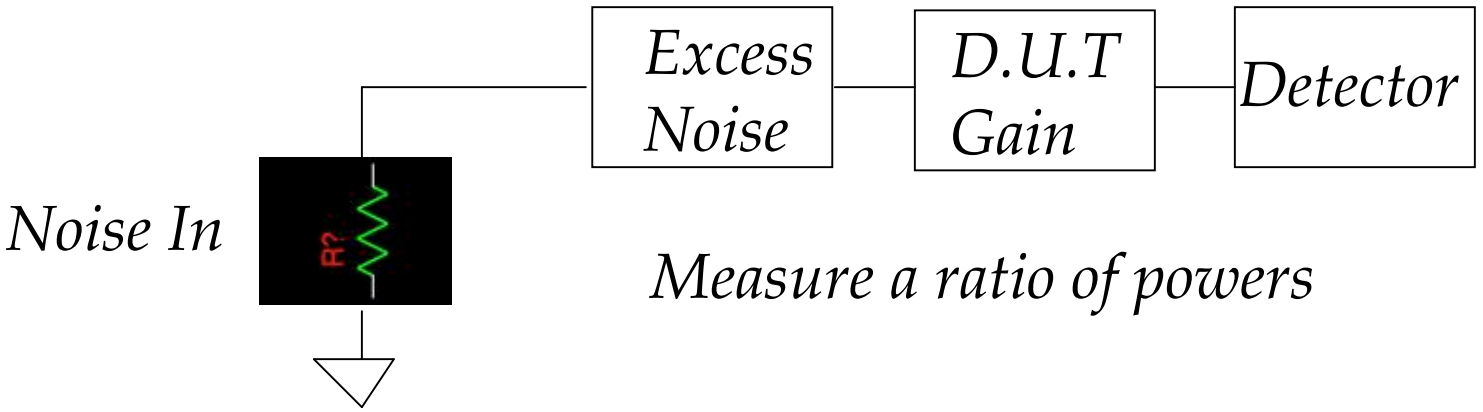
Temperature Dependent
Noise Energy = kT = joules = watt seconds

$=(1.38 \times 10^{-23}$ *joules/K)x(290 K)*
$=4 \times 10^{-21}$ *joules*
$=4 \times 10^{-18}$ *milliwatt seconds*
=-174 dBm per Hz

Have a MHz of Bandwidth then add 60 dB for -114 dBm per MHz

Noise Basics

How to Measure Noise Figure

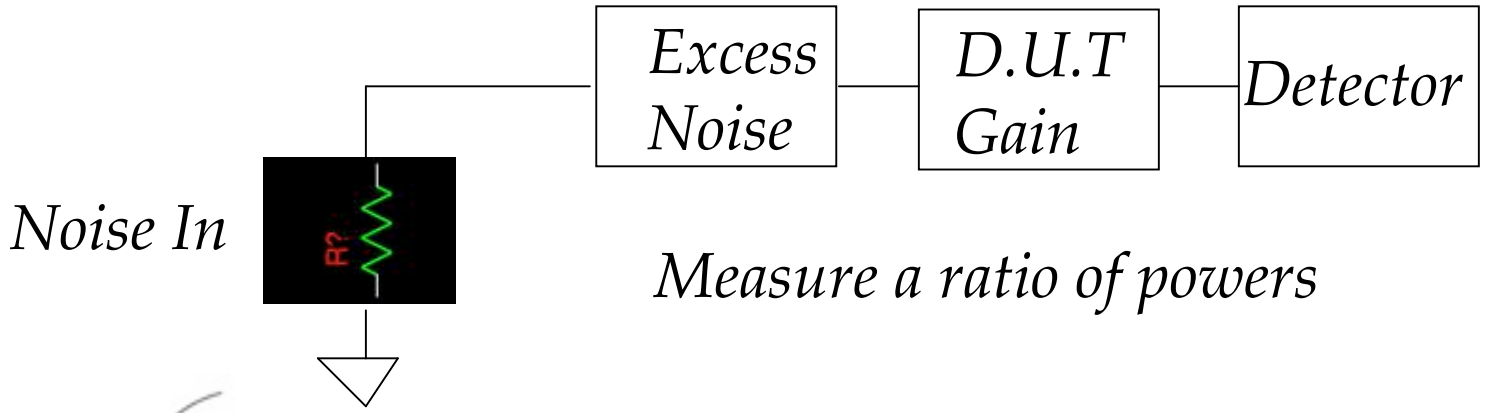


Measure a ratio of powers

excess noise off	excess noise on
D.U.T added Noise	Excess Noise x Gain
Noise In x Gain	D.U.T added Noise
	Noise In x Gain

Noise Basics

How to Measure Noise Figure

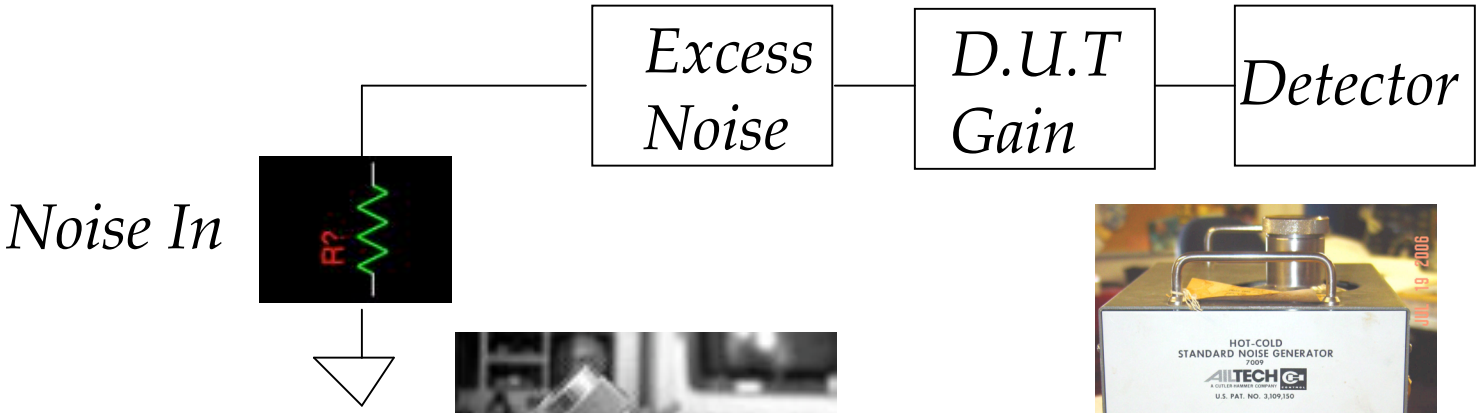


Measure a ratio of powers

$$NF = \text{Excess Noise Ratio} \times \frac{1}{\text{Measured Ratio} - 1}$$

Noise Basics

How to Measure Noise Figure

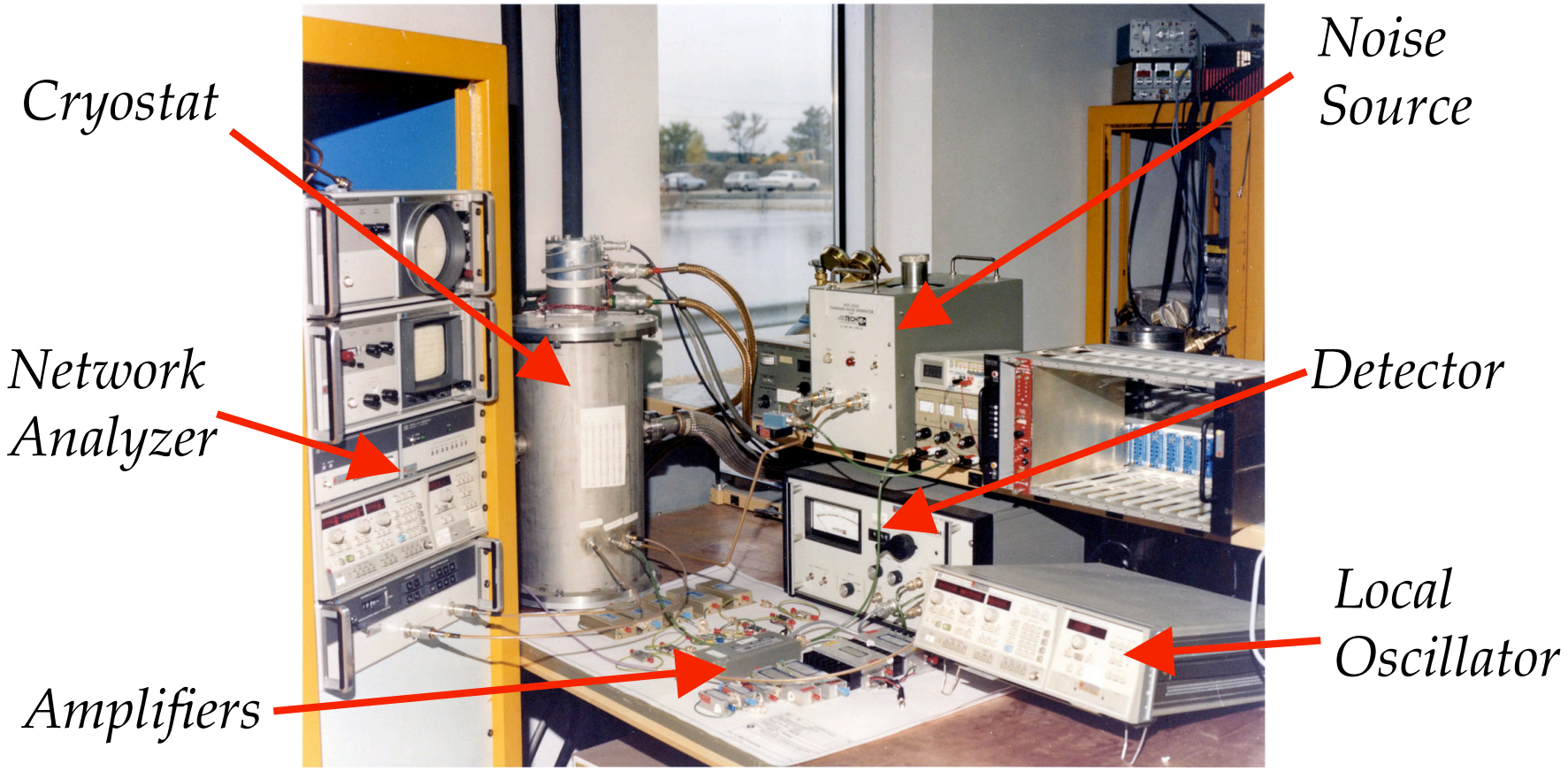


Noise Diode

Hot and Cold noise source

Noise in RF Systems

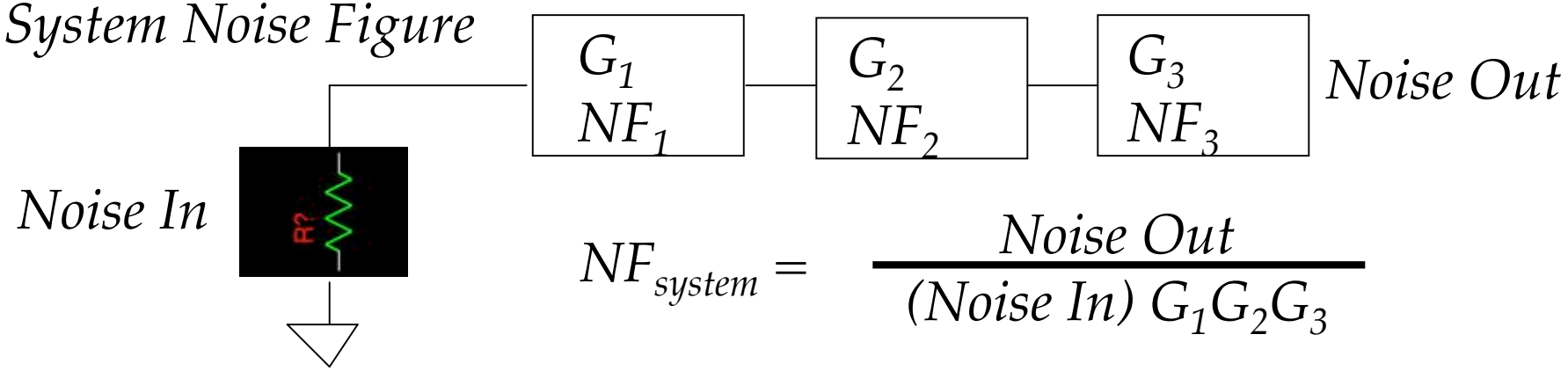
Noise Figure Test Setup



Noise in RF Systems

Noise Basics

System Noise Figure



$$NF_{system} = \frac{\text{Noise Out}}{(\text{Noise In})\, G_1 G_2 G_3}$$

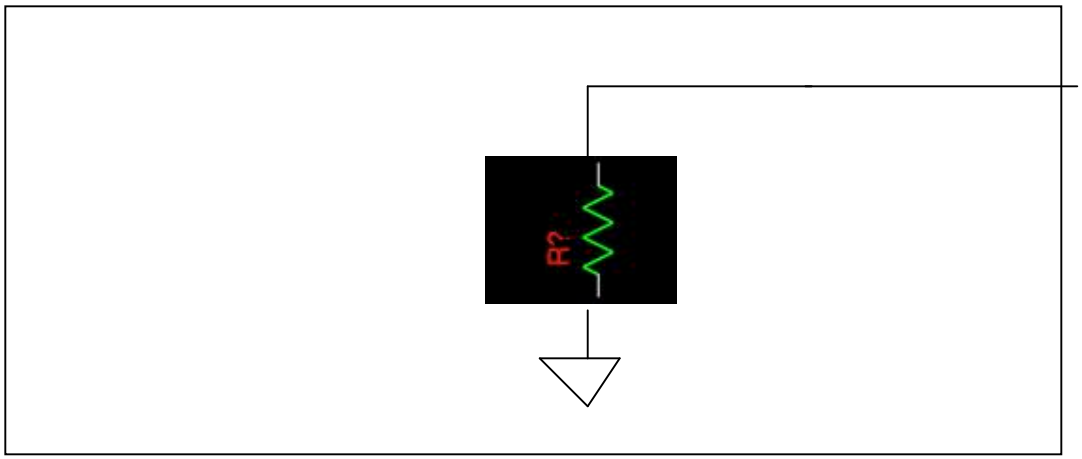
$$NF_{system} = \frac{kTBG_1G_2G_3 + (NF_1\text{-}1)kTBG_1G_2G_3}{kTBG_1G_2G_3} + \frac{(NF_2\text{-}1)kTBG_2G_3}{kTBG_1G_2G_3} + \frac{(NF_3\text{-}1)kTBG_3}{kTBG_1G_2G_3}$$

$$NF_{system} = NF_1 + \frac{NF_2 - 1}{G_1} + \frac{NF_3 - 1}{G_1\, G_2}$$

Noise in RF Systems

Mount Amplifier HERE!

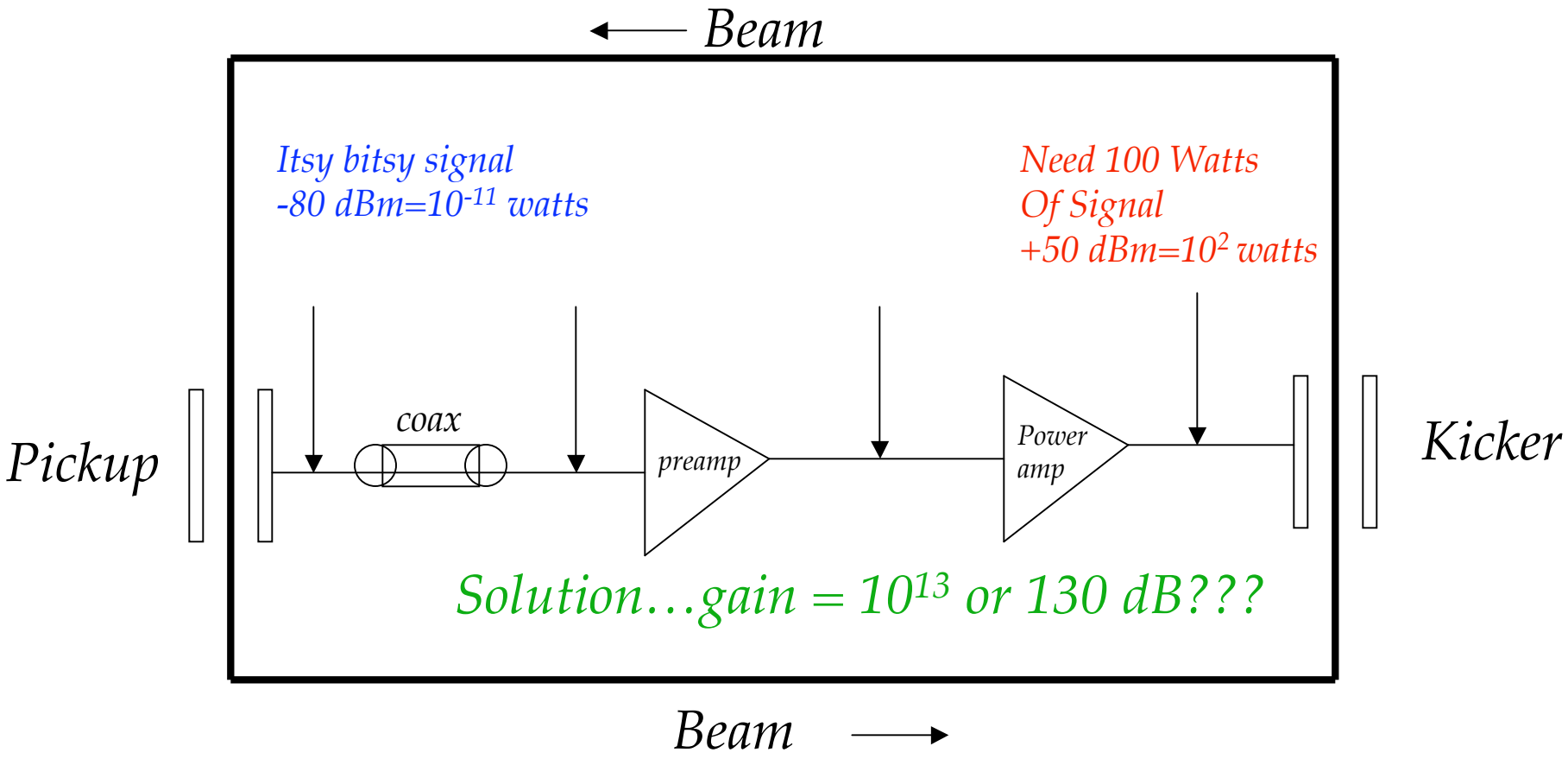
Noise in RF Systems



Look into these boxes
The impedance
looks the same!

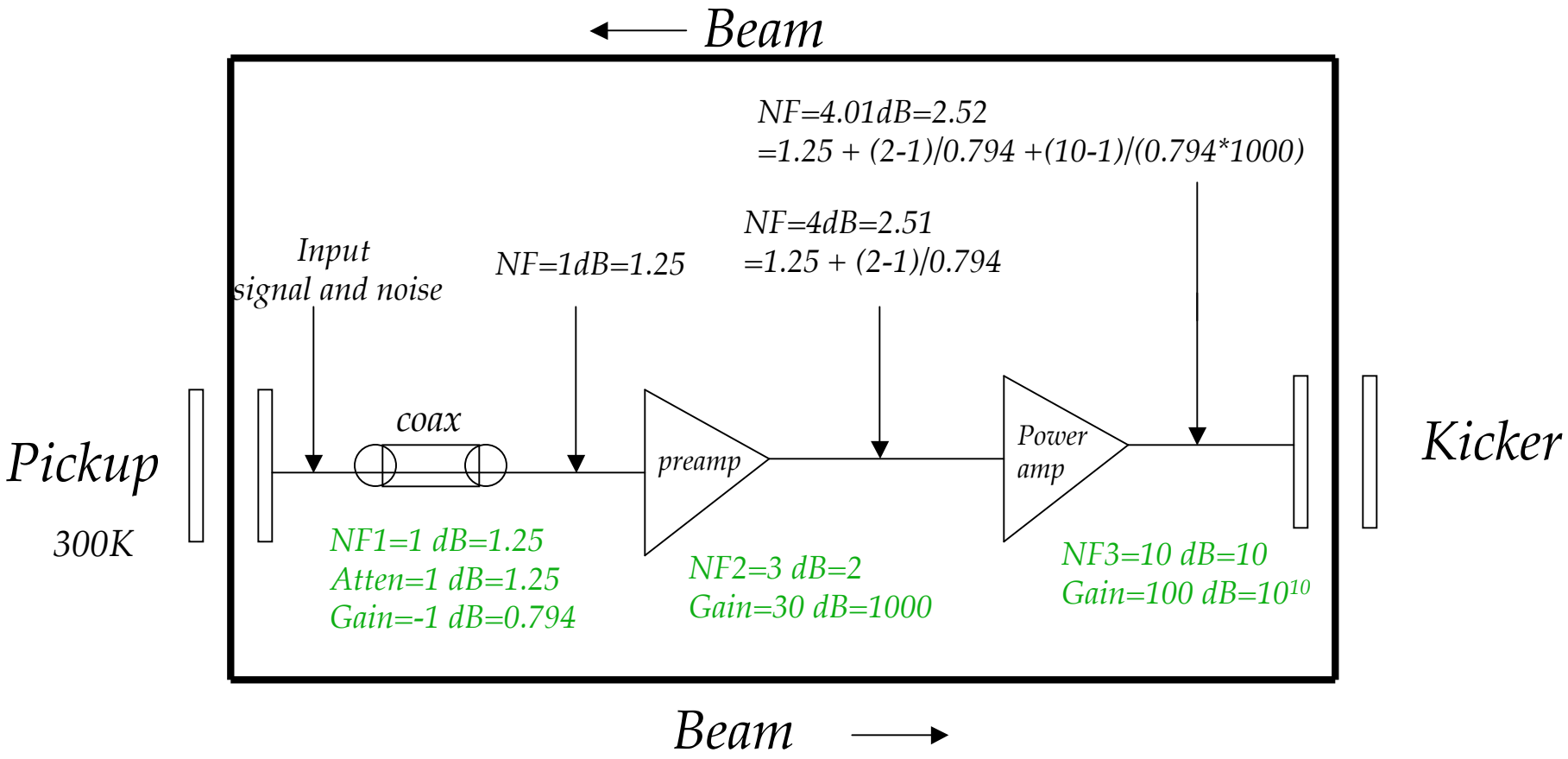
Noise in RF Systems

Typical Stochastic Cooling Feedback System



Noise in RF Systems

Typical Stochastic Cooling Feedback System



Noise in RF Systems

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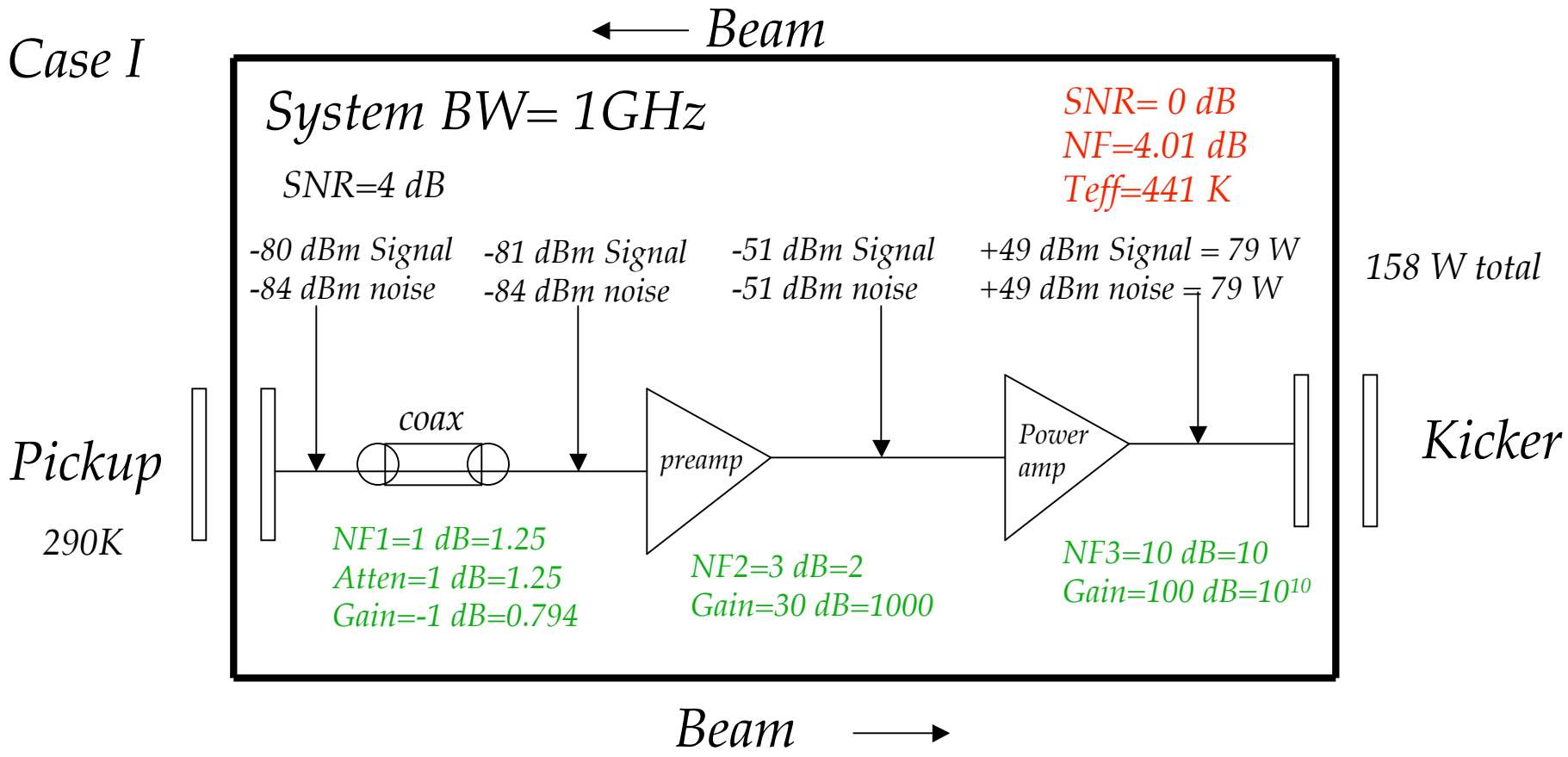

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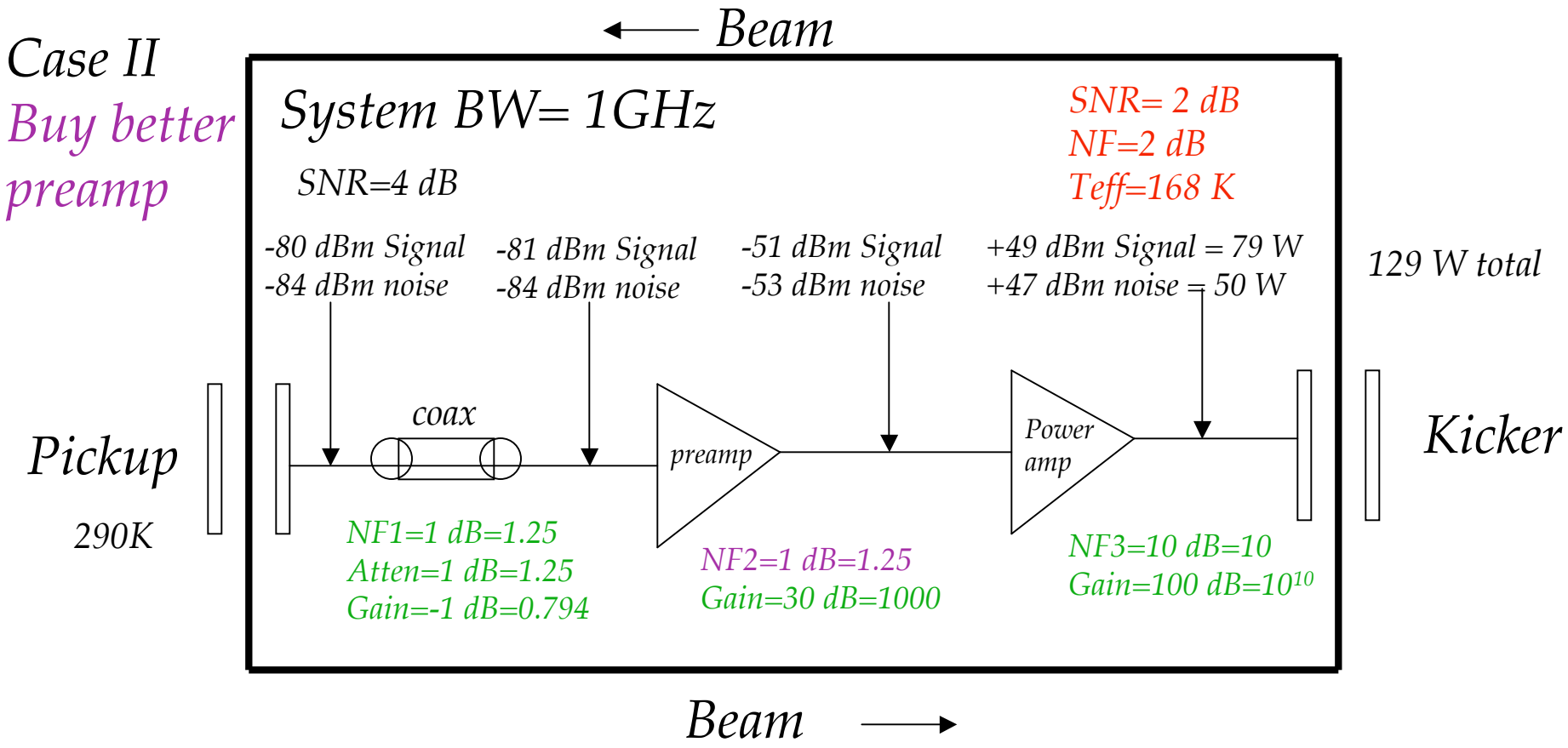

Noise in RF Systems

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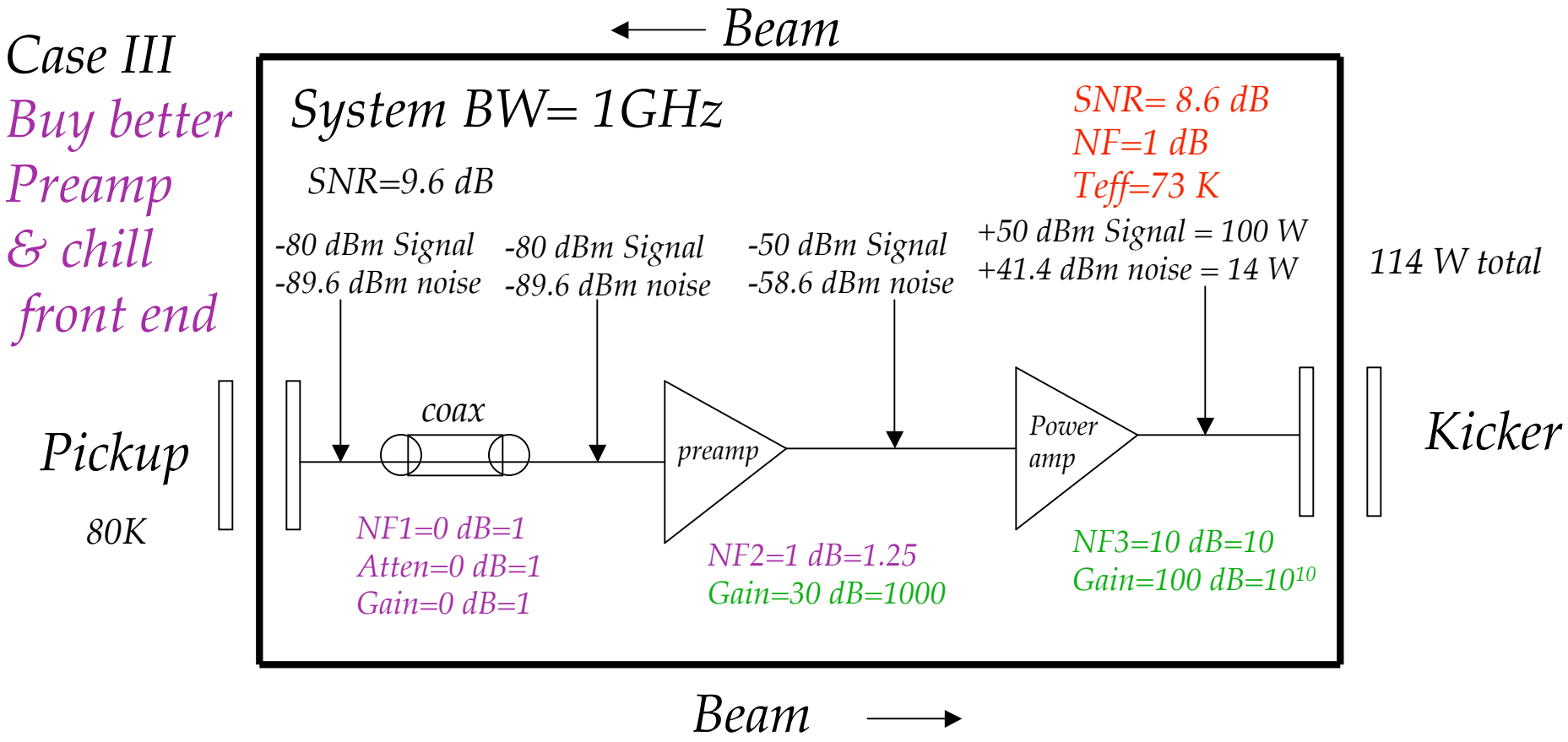


Noise in RF Systems

$$ What's the Cost $$

Power costs $100 per watt for this system

Case I: Warm pickup and 3 dB NF preamp
79 watts signal + 79 watts noise = 158 watts
Did not meet 100 watt signal minimum so must add 26% more total power for 200 Watts

Preamp cost……..$500
Power cost……$20,000
Subtotal……$20,500

Noise in RF Systems

$$ What's the Cost $$

Power costs $100 per watt for this system

Case II: Warm pickup and 1 dB NF preamp

79 watts signal + 50 watts noise = 129 watts

Did not meet 100 watt signal minimum so must add 26% more total power for 162 Watts

Preamp cost……$2000

Power cost……$16,200

Subtotal……$18,200

Noise in RF Systems

$$ What's the Cost $$

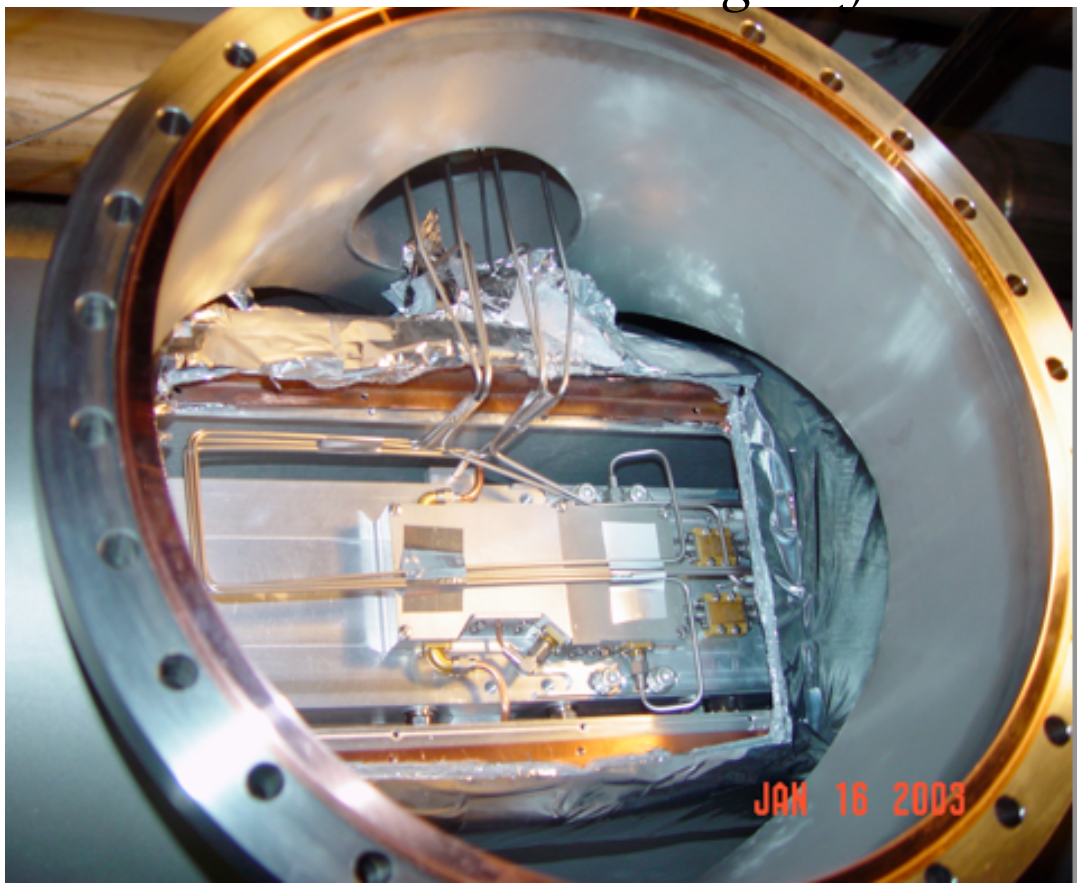
Power costs $100 per watt for this system

Case III: Cold pickup and 1 dB NF preamp
100 watts signal + 14 watts noise = 114 watts

Cryogenics ……..$50,000
Preamp cost……$2000
Power cost……$11,400
Subtotal……$63,400

Noise in RF Systems

Debuncher Stochastic Cooling Cryo Preamp



Noise in RF Systems

What if?

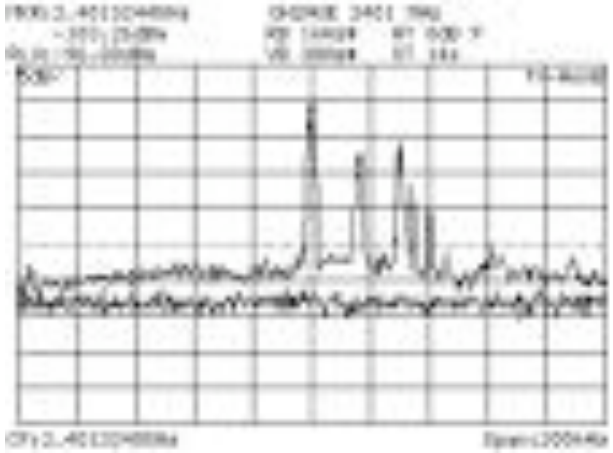
Ferrite Saturation?

Power Handling?

Tight fit?
No room
For
More Kickers

Noise Basics

Where is the noise floor?



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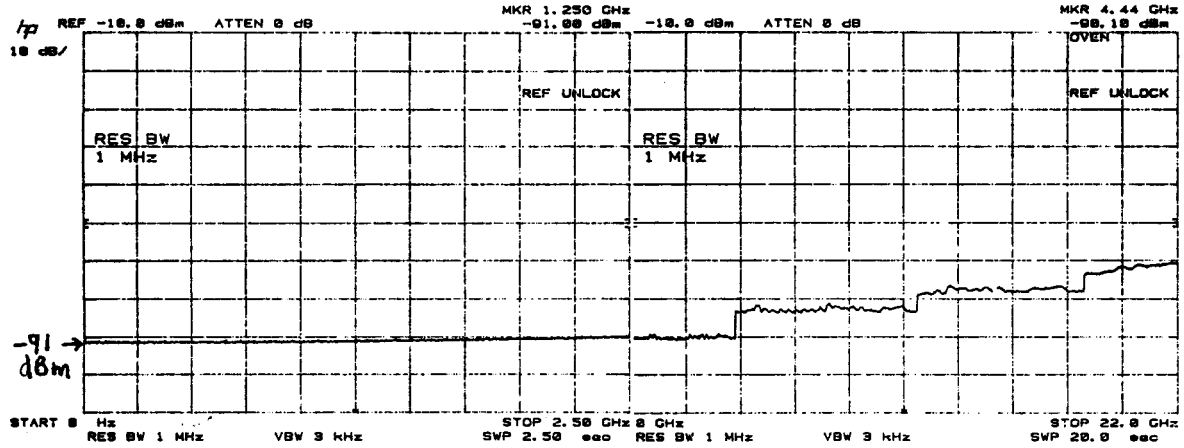
Noise in RF Systems

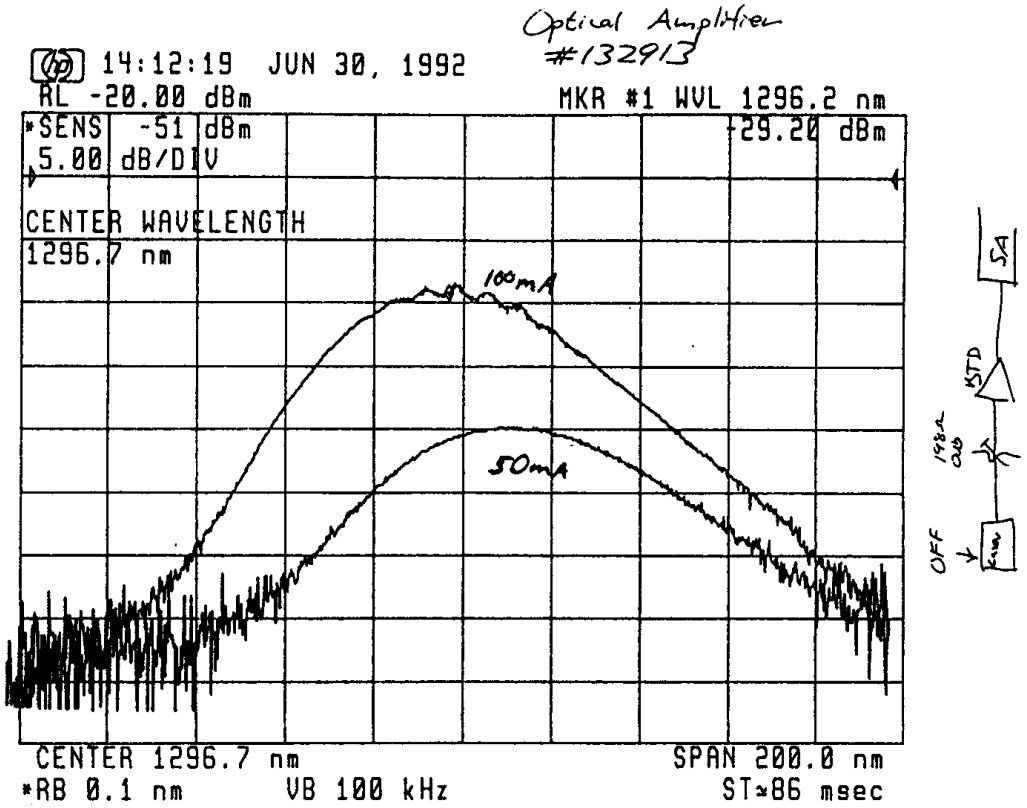
Noise Performance of Swept Frequency Spectrum Analyzer



With a Resolution Bandwidth of 1 MHz noise floor = -91 dBm
Some 23 dB worse than ideal, i.e. NF = 23 dB, Teff= 58,000 deg K

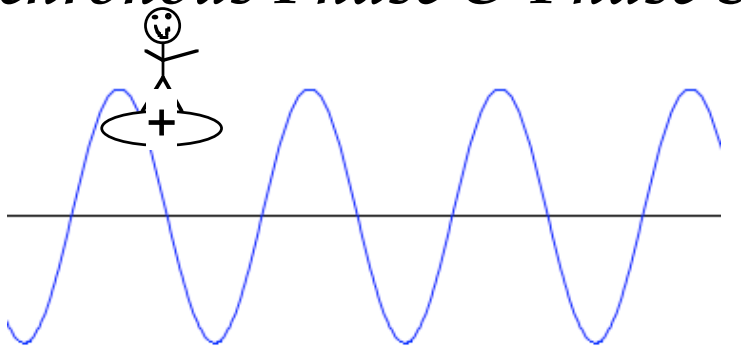
Noise in RF Systems

Optical Amplifier Noise Performance



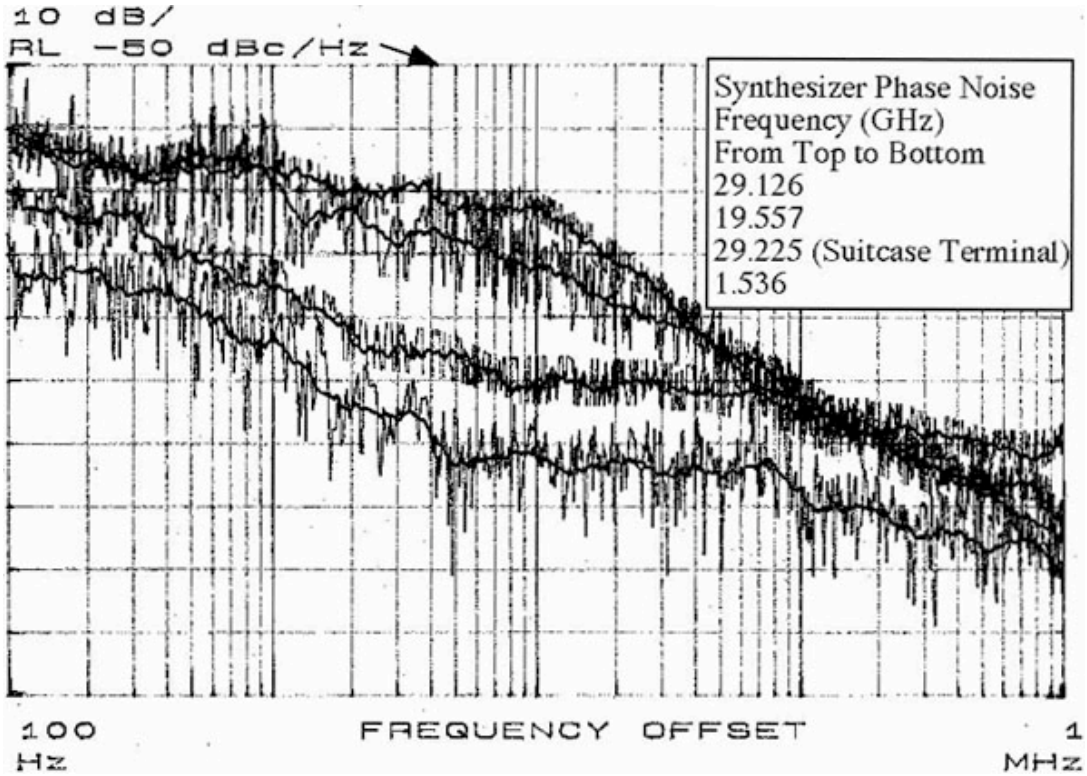
Noise in RF Systems

Synchronous Phase & Phase Stability



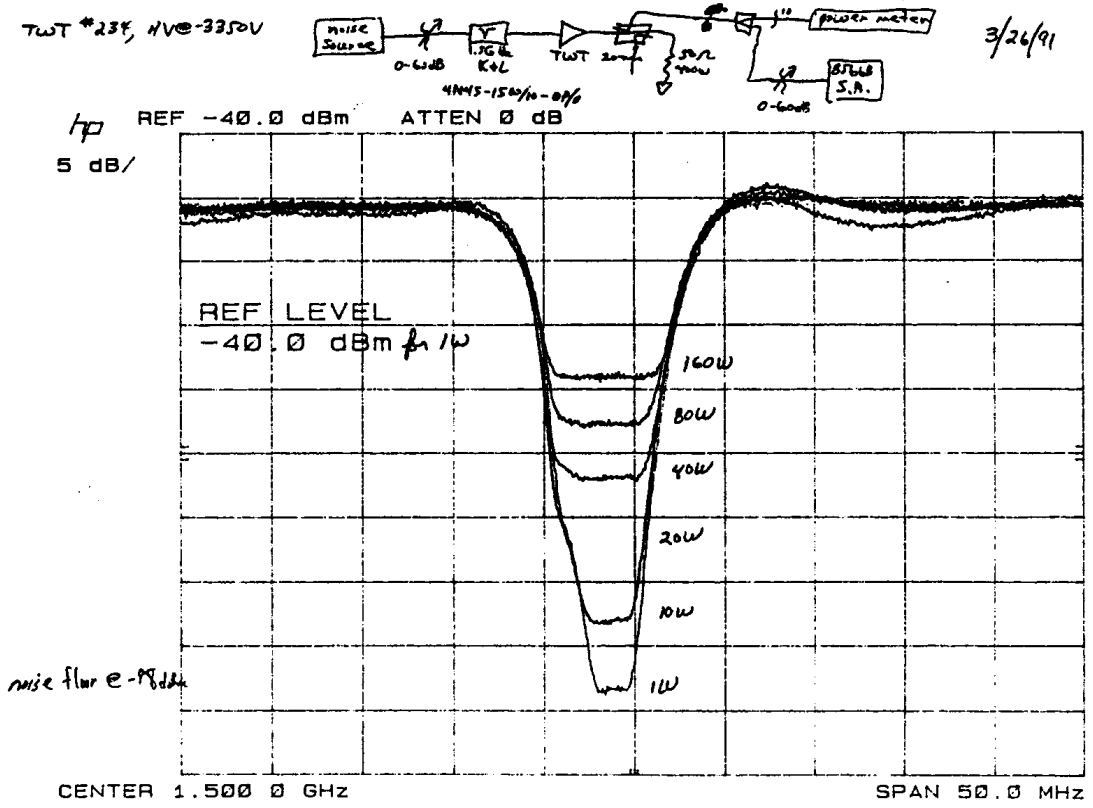
Noise in RF Systems

Plot of Phase Noise vs Frequency



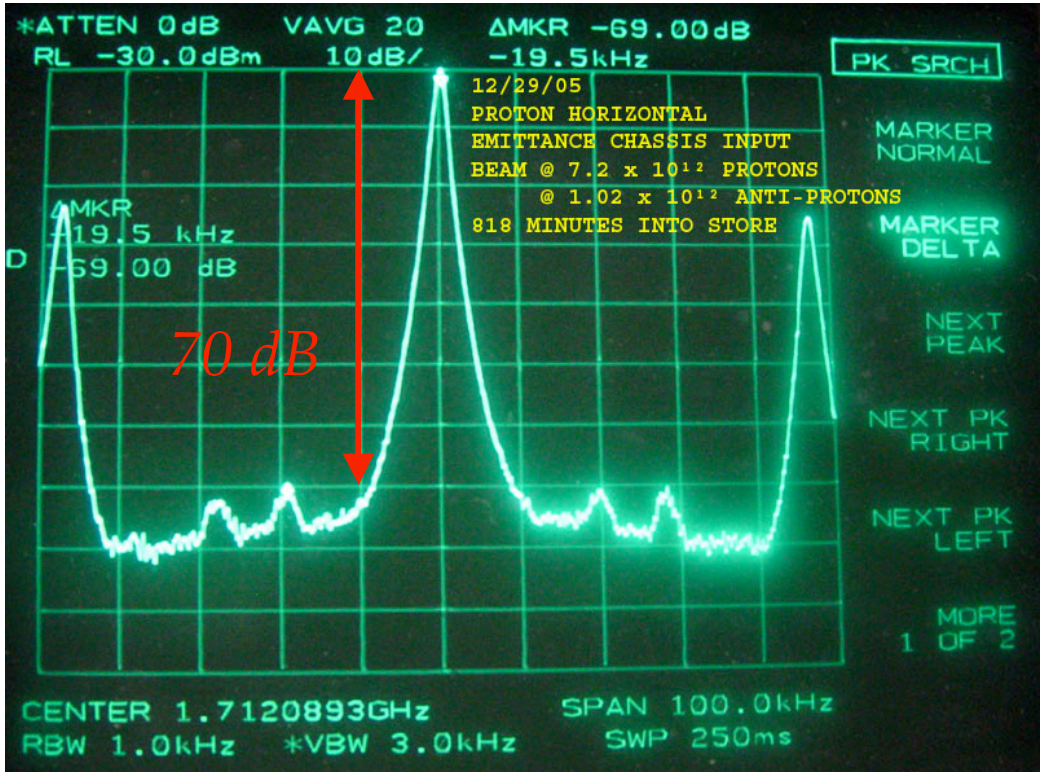
Noise in RF Systems

Intermodulation Noise in a Power Amplifier



Noise in RF Systems

Coherent Beam Signal Noise
Tevatron Schottky Signal



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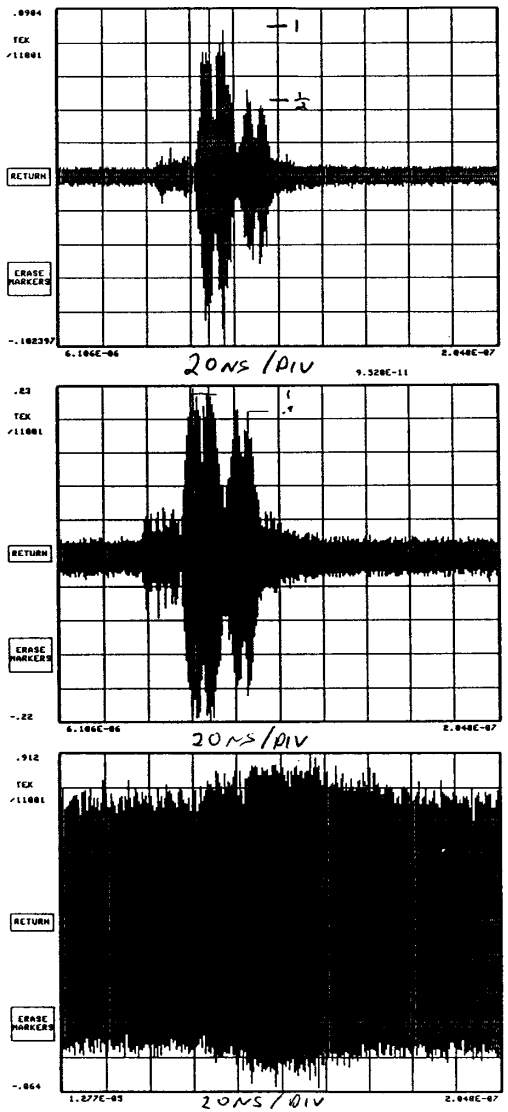


Tevatron Schottky Time Domain Signals

After pickup

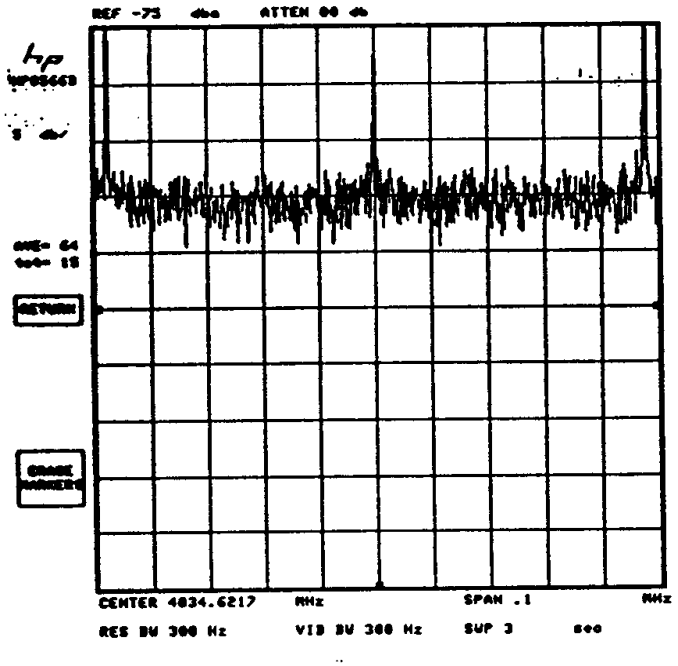
After pre-amplifier

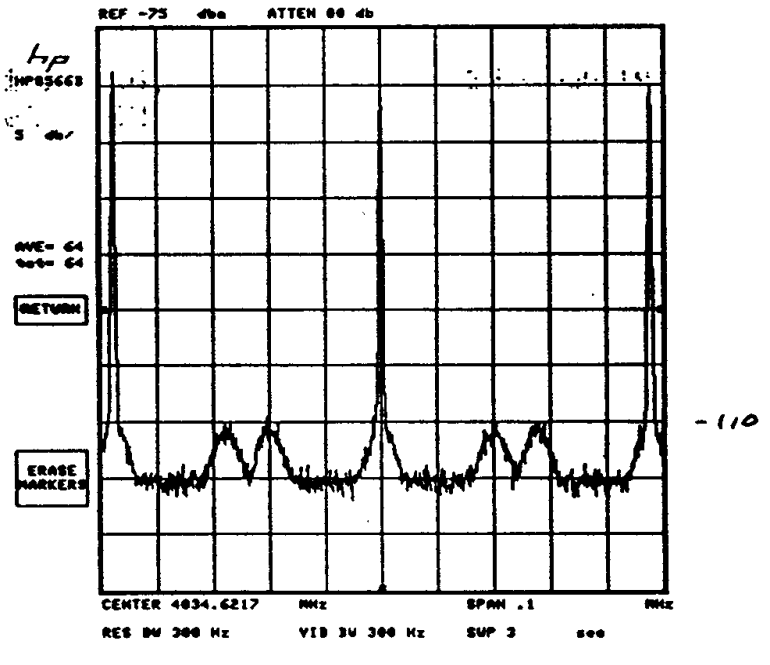
After power amplifier

Peak Power Levels can Saturate the system But not be Obvious in the Frequency Domain

Noise in RF Systems

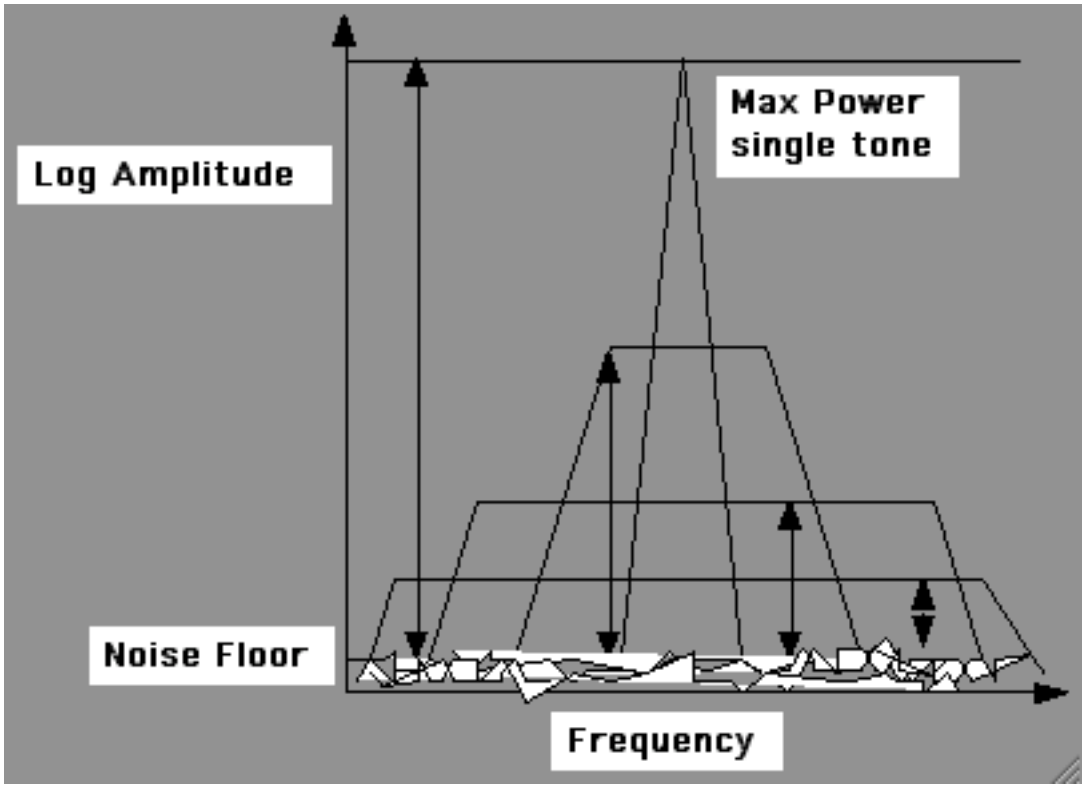
Effects by gating on Tevatron Schottky Signal





Noise in RF Systems

Dynamic Range = Max operable power/Noise floor power



Total Power
Is the
Integral across
Full bandwidth

Noise in RF Systems

Digital Connection

How many bits?

Digital is base two, so every
Bit is 2 x voltage or 6 dB

Take required dynamic range dB
and
Divide by 6 dB for number of bits!

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